A method for diffracting two beams of light using a multi-port spectrograph, such as the one shown in FIG. 12, is also provided. The beams may be diffracted simultaneously or alternatively. As already described above, the spectrograph includes a grating, a lens, a primary entrance port, a primary exit port, a secondary entrance port, and a secondary exit port.

In a first step, a first polychromatic light beam is diffracted. The first polychromatic light beam is diffracted by (1) providing said first polychromatic beam at the primary entrance port, (2) directing the first polychromatic beam with the lens toward the grating so that the first polychromatic beam is incident on the grating in the meridian plane, (3) reflecting the first polychromatic beam with the grating to form a first diffracted beam; and imaging the first diffracted beam with the lens at the primary exit port.

And, in a second step, during or alternating with the first step, a second polychromatic light beam is diffracted. The second light beam is diffracted by (1) providing the second beam at the secondary entrance port, (2) directing the second beam with the lens toward the grating so that the second beam is incident on the grating, (3) reflecting the second beam with the grating to form a second diffracted beam, and (4) imaging the second diffracted beam with the lens at the secondary exit port.

Thus, a modified concentric spectrograph with improved stray light rejection is provided. One skilled in the art will appreciate that the present invention can be practiced by other than the described embodiments, which are presented for purposes of illustration and not of limitation, and the present invention is limited only by the claims which follow.

What is claimed is:

1. A modified concentric spectrograph comprising:

a grating having an optical axis, a meridian plane, and a concave surface, said meridian plane having a first side and a second side;

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, said optical axes being substantially coaxial;

a primary entrance port being located substantially out of said meridian plane toward said first side; and

a primary exit port being located substantially out of said meridian plane toward said second side for receiving an order of light that maximizes throughput and minimizes astigmatism.

2. The spectrograph of claim 1 wherein at least one of said primary ports is near said planar surface of said lens.

3. The spectrograph of claim 1 wherein said primary entrance port has a cross-sectional area, and wherein a majority of said cross-sectional area is on said first side of said meridian plane.

4. The spectrograph of claim 1 wherein said primary entrance port has a center, and wherein said center is on said first side of said meridian plane.

5. The spectrograph of claim 3 wherein said primary exit port has a cross-sectional area, and wherein a majority of said cross-sectional area is on said second side of said meridian plane.

6. The spectrograph of claim 1 wherein said primary exit port has a center, and wherein said center is on said second side of said meridian plane.

7. The spectrograph of claim 1 wherein said primary entrance port and said primary exit port are located at substantially the same perpendicular distance from said meridian plane.

8. The spectrograph of claim 1 wherein:

said entrance port is for receiving polychromatic light from a source, said spectrograph further comprising:

a housing for preventing stray light from contaminating said polychromatic light in said housing.

9. The spectrograph of claim 1 further comprising at least one optical filter positioned near one of said ports.

10. The spectrograph of claim 1 further comprising at least one optical filter positioned between one of said ports and said planar surface of said lens.

11. The spectrograph of claim 1 further comprising:

a secondary entrance port; and

a reflective surface between said primary entrance port and said lens.

12. The spectrograph of claim 11 wherein said reflective surface is planar and has an axis normal to said reflective surface, said axis forming an angle with said grating optical axis, said angle being about 45°.

13. The spectrograph of claim 1 further comprising:

a secondary exit port; and

a reflective surface between said primary exit port and said lens.

14. The spectrograph of claim 13 wherein said reflective surface is planar and has an axis normal to said reflective surface, said axis forming an angle with said grating optical axis, said angle being about 45°.

15. A modified concentric spectrograph comprising:

a grating having an optical axis, a meridian plane, and a concave surface;

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, said lens optical axis is substantially coaxial with said grating optical axis, and a primary focal plane is formed perpendicular to said optical axis facing said planar surface of said lens;

a primary entrance port near said primary focal plane at an intersection between a first axis and a second axis, wherein said first axis is parallel to, and offset in a first direction from, said meridian plane and said second axis is perpendicular to said meridian plane and offset from said optical axis; and

a primary exit port near said primary focal plane located at a second perpendicular distance from said meridian plane, in a second direction opposite said first direction for receiving an order of light that maximizes throughput and minimizes astigmatism.

16. The spectrograph of claim 15 wherein said entrance port is for receiving light and wherein said grating diffracts said light into at least one non-zero diffraction order, said exit port being positioned along said first axis to receive a portion of said non-zero diffraction order.

17. The spectrograph of claim 16 wherein said non-zero order is an order which is imaged most closely to said optical axis.

18. The spectrograph of claim 16 wherein said non-zero order is a negative first order.

19. The spectrograph of claim 15 wherein said exit port is elongated along said first axis.

20. The spectrograph of claim 15 further comprising at least one optical filter positioned between one of said ports and said lens.

21. The spectrograph of claim 15 wherein said entrance port is for receiving light from a primary light source, said spectrograph further comprising at least one optical filter between said light source and said entrance port.

22. The spectrograph of claim 15 wherein said entrance port is for receiving light from a primary light source, said spectrograph further comprising a housing for preventing light coming from a secondary light source external to said housing from contaminating said light from said primary source in said housing.

23. The spectrograph of claim 22 wherein at least one of said ports is mounted to said housing.

24. The spectrograph of claim 15 further comprising:

a secondary entrance port; and

a reflective surface between said primary entrance port and said lens, wherein said reflective surface forms a modified focal plane in which said secondary entrance port is located.

25. The spectrograph of claim 15 further comprising a first body comprising an optically transmissive material, said transmissive material having an index of refraction, said first body having at least three planar surfaces, wherein any pair of said first body planar surfaces intersect to form a respective line of intersection, each respective line of intersection being substantially parallel to the other lines, a first of said first body planar surfaces being at least partially located between said primary entrance port and said lens and having a reflective surface disposed on said first plane forming a modified focal plane, a second of said first body planar surfaces facing said planar surface of said lens, and a third of said first body planar surfaces facing said modified focal plane.

26. The spectrograph of claim 25 further comprising a second body comprising said optically transmissive material, said second body having at least two substantially parallel planar surfaces, a first of said second body parallel planar surfaces facing said primary exit port, a second of said second body parallel planar surfaces facing said lens.

27. The spectrograph of claim 25 wherein an angle between said optical axis of said grating and an axis normal to said first of said first body planar surfaces is about 45°.

28. The spectrograph of claim 27 wherein said second surface of said first body is fixedly attached to said planar surface of said lens.

29. The spectrograph of claim 25 further comprising at least one optical filter positioned between said lens and said first body.

30. The spectrograph of claim 26 further comprising at least one optical filter positioned between said lens and said second body.

31. The spectrograph of claim 26 wherein said second surface of said second body is fixedly attached to said planar surface of said lens.

32. The spectrograph of claim 31 further comprising an adhesive having an index of refraction that is substantially the same as the index of refraction of said second body for fixedly attaching said second body to said lens.

33. The spectrograph of claim 26 wherein said second surface of said second body and said lens are integral.

34. The spectrograph of claim 25 further comprising a secondary exit port and a reflective surface between said primary exit port and said lens, wherein said reflective surface forms a modified focal plane.

35. The spectrograph of claim 15 further comprising a first body comprising an optically transmissive material, said optically transmissive material having an index of refraction, said first body having at least three planar surfaces, wherein any pair of said first body planar surfaces intersect to form a respective line of intersection, each respective line of intersection being substantially parallel to the other lines, a first of said planes being located between said primary exit port and said lens and having a reflective surface disposed on said first plane, thereby forming a modified focal plane, a second of said first body planar surfaces facing said lens planar surface, and a third of said first body planar surfaces facing said modified focal plane.

36. The spectrograph of claim 35 further comprising a second body comprising said optically transmissive material, said second body having at least two substantially parallel planar surfaces, a first of said second body parallel planar surfaces facing said primary entrance port, a second of said second body parallel planar surfaces facing said lens.

37. The spectrograph of claim 35 wherein an angle between said optical axis of said grating and an axis normal to said first of said reflective surface is about 45°.

38. The spectrograph of claim 35 wherein said second surface of said first body is fixedly attached to said planar surface of said lens.

39. The spectrograph of claim 35 further comprising at least one optical filter positioned between said lens and said first body.

40. The spectrograph of claim 36 further comprising at least one optical filter positioned between said lens and said second body.

41. The spectrograph of claim 36 wherein said second face of said second body is fixedly attached to said planar surface of said lens.

42. The spectrograph of claim 41 further comprising an adhesive having an index of refraction that is substantially the same as the index of refraction of said second body for fixedly attaching said second body to said lens.

43. The spectrograph of claim 35 wherein said second body and said lens are integral.

44. The spectrograph of claim 15 wherein at least one of said ports is substantially in one of said focal planes.

45. The spectrograph of claim 15 wherein said convex surface has a center of curvature and said concave surface has a center of curvature, and wherein said centers of curvature are substantially concentric.

46. A modified concentric spectrograph with reduced stray light, said spectrograph comprising:

a concave grating for dispersing light having an optical axis, a meridian plane, and a concave surface;

a lens having an optical axis, a planar surface, and a convex surface, wherein said optical axes are substantially coaxial, said convex surface is facing said concave surface, and wherein a primary focal plane is formed facing said planar surface of said lens;

an entrance port near said focal plane for permitting light to enter said spectrograph along an optical path, said entrance port being substantially located at a distance from said meridian plane in a first direction, said lens directing said light from said entrance port toward said meridian plane and said grating surface for diffraction; and

an exit port located near said focal plane for permitting a portion of said light to exit said spectrograph after said light is diffraction by said grating, said lens imaging said portion of said light at said exit port for receiving an order of light that maximizes throughput and minimizes astigmatism.

47. The spectrograph of claim 46 wherein said entrance port and said exit port are optically connected by an optical path.

48. The spectrograph of claim 46 wherein at least some of said portion of said light is a non-zero order of diffracted light.

49. The spectrograph of claim 48 wherein said non-zero order of diffracted light is an order that is imaged most closely to said grating optical axis at said focal plane.

50. The spectrograph of claim 48 wherein said non-zero order is a negative first order.

51. The spectrograph of claim 46 wherein said exit port is at said perpendicular distance from said meridian plane in a direction opposite said first direction.

52. The spectrograph of claim 46 wherein said lens has an optical axis that is parallel to and offset from said grating optical axis to improve image quality and reduce stray light at said exit port.

53. The spectrograph of claim 46 further comprising a housing in which said lens and said grating are placed, said housing for preventing light coming from any secondary light source outside said housing from contaminating said light in said housing.

54. The spectrograph of claim 46 further comprising:

a reflective surface between said entrance port and said lens, thereby forming a modified focal plane; and

a secondary entrance port near said modified focal plane for receiving light from a light source.

55. The spectrograph of claim 46 further comprising:

a reflective surface between said exit port and said lens, thereby forming a modified focal plane; and

a secondary exit port near said modified focal plane for permitting dispersed light to exit said spectrograph.

56. The spectrograph of claim 46 wherein said primary entrance port and said primary exit port are located near a primary focal plane near said planar surface of said lens.

57. The spectrograph of claim 46 wherein said convex surface has a center of curvature and said concave surface has a center of curvature that is substantially concentric with said convex surface center.

58. A modified concentric spectrograph comprising:

a grating having an optical axis, a meridian plane, and a concave surface;

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, said optical axes are substantially collinear and said surfaces are substantially concentric, and a primary focal plane is formed perpendicular to said optical axis facing said planar surface of said lens;

a primary entrance port near said primary focal plane at an intersection between a first primary axis and a second primary axis, wherein said first primary axis is parallel to and offset from said meridian plane and said second primary axis is perpendicular to said meridian plane and offset from said grating optical axis;

a primary exit port near said primary focal plane located at a first perpendicular distance from said meridian plane, said first perpendicular distance being in a second direction opposite said first direction for receiving an order of light that maximizes throughput and minimizes astigmatism;

a secondary entrance port near said primary focal plane at an intersection between a first secondary axis and a second secondary axis, wherein said first secondary axis is parallel to and offset from said meridian plane and said second secondary axis is perpendicular to said meridian plane and offset from said grating optical axis; and

a secondary exit port near said primary focal plane located at a second perpendicular distance from said meridian plane in said second direction.

59. The spectrograph of claim 58 wherein said primary entrance port is positioned to receive polychromatic light and wherein said grating diffracts said light into at least one non-zero diffraction order, said primary exit port being positioned to receive a portion of said non-zero diffraction order.

60. The spectrograph of claim 59 wherein said non-zero order is an order which is imaged most closely to said optical axis of said grating.

61. The spectrograph of claim 60 wherein said non-zero order is a negative first order.

62. The spectrograph of claim 58 wherein said primary entrance port is for receiving light from a primary light source, said spectrograph further comprising a housing around in which said grating and said lens is placed.

63. The spectrograph of claim 58 wherein at least one of said ports is in said primary focal plane.

64. A modified concentric spectrograph comprising:

a grating having an optical axis, a meridian plane, and a concave surface;

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, said optical axes are substantially collinear, and wherein a primary focal plane is formed perpendicular to said optical axis facing said planar surface;

a first body comprising an optically transmissive material, said first body having at least three planar surfaces, wherein any pair of said first body planar surfaces intersect to form a respective line of intersection, each respective line of intersection being substantially parallel to the other lines, a first of said first body planar surfaces being located between said primary focal plane and said planar surface of said lens and having a reflective surface disposed thereon, a second of said first body planar surfaces facing said planar surface of said lens, and a third of said first body planar surfaces facing a modified focal plane, said reflective surface forming said modified focal plane at an optical length from said planar lens surface;

a primary entrance port near said modified focal plane at an intersection between a first axis and a second axis, wherein said first axis is parallel to and offset in a first direction from said meridian plane and said second axis is perpendicular to said meridian plane; and

a primary exit port near said primary focal plane located at a first perpendicular distance from said meridian plane, said first perpendicular distance being in a second direction opposite said first direction for receiving an order of light that maximizes throughput and minimizes astigmatism.

65. The spectrograph of claim 64 further comprising a second body comprising said optically transmissive material, said second body having at least two substantially parallel planar surfaces, a first of said second body parallel planar surfaces facing said primary exit port, a second of said second body parallel planar surfaces facing said lens.

66. A method for dispersing light comprising:

passing polychromatic light through an entrance port located substantially on a first side of and at a perpendicular distance from a meridian plane of a concave diffraction grating;

directing said polychromatic light with a lens toward said grating so that said light is incident on said grating at least at said meridian plane;

diffracting said light with said diffraction grating, thereby dispersing said light; and

imaging said dispersed light with said lens at an exit port located substantially on a second side of said meridian

plane for receiving an order of light that maximizes throughput and minimizes astigmatism.

67. A method for diffracting two beams of light using a modified concentric spectrograph, said spectrograph comprising:

a grating having an optical axis, a meridian plane having a first side and a second side, and a concave surface,

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface faces said concave surface, said optical axes being substantially coaxial,

a primary entrance port being located substantially on said first side of said meridian plane,

a primary exit port being located substantially on said second side of said meridian plane,

a secondary entrance port being located substantially on said first side of said meridian plane, and

a secondary exit port being located substantially on said second side of said meridian plane; said method comprising:

diffracting a first light beam comprising:

providing said first beam at said primary entrance port,

directing said first beam with said lens toward said grating so that at least a portion of said first beam is incident on said grating surface,

reflectively diffracting said first beam with said grating to form a first diffracted beam, and

imaging said first diffracted beam with said lens at said primary exit port; and

diffracting a second light beam comprising:

providing said second beam at said secondary entrance port,

directing said second beam with said lens toward said grating so that at least a portion of said second beam is incident on said grating surface,

reflectively diffracting said second beam with said grating to form a second diffracted beam, and

imaging said second diffracted beam with said lens at said secondary exit port.

68. A method for diffracting two beams of light using a modified concentric spectrograph, said spectrograph comprising:

a grating having an optical axis, a meridian plane having a first side and a second side, and a concave surface,

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, being subal axes being substantially coaxial,

a primary entrance port being located substantially on said first side of said meridian plane,

a primary exit port being located substantially on said second side of said meridian plane for receiving an order of light that maximizes throughput and minimizes astigmatism,

a secondary entrance port being located substantially on said second side of said meridian plane, and

a secondary exit port being located substantially on said first side of said meridian plane; said method comprising:

diffracting a first light beam comprising:

providing said first beam at said primary entrance port,

directing said first beam with said lens toward said grating so that at least a portion of said first beam is incident on said grating surface,

reflectively diffracting said first beam with said grating to form a first diffracted beam, and

imaging said first diffracted beam with said lens at said primary exit port; and

diffracting a second light beam comprising:

providing said second beam at said secondary entrance port,

directing said second beam with said lens toward said grating so that at least a portion of said second beam is incident on said grating surface,

reflectively diffracting said second beam with said grating to form a second diffracted beam, and

imaging said second diffracted beam with said lens at said secondary exit port.

69. A concentric spectrograph for spectrally dispersing polychromatic light comprising:

a grating having a concave surface and an optical axis;

a lens having a substantially planar surface, a convex surface, and an optical axis, wherein said convex surface is facing said concave surface, said optical axes are substantially coaxial, said convex and concave surfaces are substantially concentric, and wherein said lens and said grating are positioned at a distance to form a primary focal plane;

a first port facing said planar surface of said lens;

a first body comprising an optically transmissive material, said transmissive material having an index of refraction, said first body having at least three planar surfaces, wherein any pair of said first body planar surfaces intersect to form a respective line of intersection, each respective line of intersection being substantially parallel to the other lines, a first of said first body planar surfaces being at least partially located between said first port and said lens and having a reflective surface disposed on said first plane forming a modified focal plane, a second of said first body planar surfaces facing said planar surface of said lens, and a third of said first body planar surfaces facing said modified focal plane; and

a second port facing said planar surface of said lens and being located near said primary focal plane for receiving an order of light that maximizes throughput and minimizes astigmatism.

70. The spectrograph of claim 69 further comprising a second body comprising said optically transmissive material, said second body having at least two substantially parallel planar surfaces, a first of said second body parallel planar surfaces facing said second port, a second of said second body parallel planar surfaces facing said lens.

71. The spectrograph of claim 69 wherein an angle between said optical axis of said grating and an axis normal to said first of said first body planar surfaces is about 45°.

72. The spectrograph of claim 69 wherein said second surface of said first body is fixedly attached to said planar surface of said lens.

73. The spectrograph of claim 72 further comprising an adhesive having an index of refraction that is substantially the same as the index of refraction of said optically transmissive material for fixedly attaching said first body to said lens.

74. The spectrograph of claim 69 wherein said first body and said lens are integral at said second surface of said first body.

75. The spectrograph of claim 70 wherein said second surface of said second body is fixedly attached to said planar surface of said lens.

76. The spectrograph of claim 75 further comprising an adhesive having an index of refraction that is substantially the same as the index of refraction of said second body for fixedly attaching said second body to said lens.

77. The spectrograph of claim 69 further comprising one or more optically transmissive plates placed so that said polychromatic light passes through said at least one of said plates for varying the position of one of said focal planes.

78. The spectrograph of claim 77 wherein said at least one of said plates is placed between one of said ports and said lens.

79. The spectrograph of claim 77 wherein said at least one of said plates is placed between one of said bodies and one of said ports.

80. The spectrograph of claim 77 wherein said at least one of said plates is placed between one of said bodies and said lens.

81. The spectrograph of claim 77 wherein said at least one of said plates has an index of refraction which is different from said optical bodies.

82. The spectrograph of claim 81 wherein said at least one of said plates comprises sapphire.

83. The spectrograph of claim 77 further comprising at least one optical filter positioned between said lens and one of said bodies.

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